

Vashon Drift (unit Qvlc), of which the coastal bluff exposures southeast of West Point constitute the type section (Mullineaux Coarser advance outwash deposits (unit Qva) mark direct, active ice-sheet deposition by streams flowing from the advancing glacier. Sandy advance outwash deposits at least a few tens of meters thick (and locally as thick as 90 m) underlie the broad uplands in the central part of the map area. The outwash deposits inundated the pre-Vashon-age topography of the lowland, resulting in a south-sloping surface that is now about 150 m (490 ft) high at this latitude elsewhere across the Puget Lowland (Booth, 1994); this surface only achieves a maximum elevation of 110 m (360 ft) in the Seattle NW map area owing to synglacial

with the City of Seattle through 1999 (Shannon & Wilson, Inc.,

where extensive: at West Point, along the coastline between

Shilshole Bay Marina and Golden Gardens Park, and in the lee of the hill at Magnolia. Except for one small, nearly unique patch of

unaltered shoreline at the north end of Golden Gardens Park,

these deposits are almost everywhere overlain by fill, which at some localities is over 10 m thick. Fill also overlies tideflat

deposits (unit Qtf) east and southeast of Magnolia, where borings

typically penetrate 6 m of sand-and-clay fill over as much as 15 m

Human Modification of the Landscape

Several areas within the map area have been modified by the

addition of fill, by grading, or by the removal of sand and gravel.

The affected areas visible at map scale include the entire Interbay

area, a former tidal channel between Magnolia and the rest of

Seattle; the regional wastewater treatment plant at West Point;

marina complexes at Shilshole Bay and at the south base of the

hill at Magnolia; a flat-graded and now-abandoned rifle range in

Discovery Park; and several school and community playfields.

Near the north tip of the hill at Magnolia, an anomalous flat-

topped ridge is the apparent legacy of early development activity,

Regional Structure and Recent Seismicity

The entire area of the Seattle NW map lies within the Seattle

Basin, the deepest of the structural blocks formed in western

Washington in Tertiary time as a result of north-south-directed

shortening in Oregon and Washington (Pratt and others, 1997;

Wells and others, 1998). The east-west striking Seattle Fault

Zone forms the border between the Seattle Basin (to the north)

and the Seattle Uplift (to the south), passing through Seattle 8 to

10 km south of the south boundary of the Seattle NW map area

1,100 years ago, land in the Seattle NW map area dropped by as

much as 1 m. The best evidence of this subsidence consists of

sub-sea-level deposits on West Point exposed by construction

excavations for expansion of the West Point sewage treatment

plant (Atwater and Moore, 1992). The plant sits on an

archaeological site that shows evidence of fault subsidence and a

tsunami. The West Point spit accreted over the past 5,000 years,

building outward by longshore drift and upward by sea-level rise.

Prior to 1,100 years ago, perimeter beach berms protected a

backbeach tidal marsh. Native Americans occupied dry ground

around the marsh and used the land as a seasonal shellfish

processing area; radiocarbon data (table 1) provide a range of

dates (4,237 calibrated yr B.P. through 150 calibrated yr B.P.) for

Native American occupation of the spit and backbeach area

(Troost and Stein, 1995). The earthquake on the Seattle Fault

1,100 years ago resulted in 1 m of subsidence and deposition of a

tsunami sand layer. Beach and shallow-marine sediments

concealed the tsunami sand until the early 1990's, when

City of Seattle using a larger scale base map, which allows a more

enhanced level of detail than previously was available. Geologic

relations shown on this map are based on several sources,

including new field mapping of outcrops and excavations,

subsurface data compiled in a digital geologic database,

topographic and geomorphic analyses, and the preexisting

geologic map of the Seattle area (Waldron and others, 1962).

Across most of the map area, geologic contacts and lithologic

descriptions have changed somewhat from the preexisting map, as

a result of both the dramatic increase in data from construction-

related exposures and the revised understanding of the regional

Pacific Northwest Center for Geologic Mapping Studies at the

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The mapping and associated database were completed by the

stratigraphic framework of the Puget Lowland.

Map Summary and Acknowledgements

This map is the first of four geologic maps prepared for the

excavation for the treatment plant exposed the layer.

During a large (M ~7.5) earthquake on the Seattle Fault

as shown by topographic maps from the early 1900's.

(see Troost and others, 2005).

of refuse before encountering organic silt and sand in place.

Modern beach deposits (unit Qb) are shown on this map only

2000) are included on this map for reference.

and northwest of the "Ballard Locks" in a near-vertical 30-m-high cliff that faces Shilshole Bay Marina The matrix of the till differs from place to place in relative proportions of silt, sand, and (usually sparse) clay. The till mostly is gravelly silty sand to gravelly sandy silt; in many places, it is crudely stratified and contains lenses of sand, gravel, and silt. Cobbles and boulders are scattered throughout the till; boulders more than 3 m in diameter are rare. Unoxidized till is light gray and compact; where oxidized, till is light yellowish gray and generally is moderately dense. Although a weak brown soil is developed on the till, oxidation rarely extends more than Vashon till typically is very dense and has a fine-grained

still filled the Strait of Juan de Fuca.

This material has been mapped as the Lawton Clay Member of the

As ice covered the region, till (unit Qvt) was deposited by the melt-out of debris at the base of the glacier. The ground surface underlain by both advance outwash deposits and till locally is fluted with elongated hills that have a weak but uniform northsouth orientation (azimuth approx 177°) across the map area. The fluting is expressed more clearly in the southern half of the map area, on the hill at Magnolia. Immediately north of the Ship Canal, ridges and valleys trend in the same orientation but are more subdued than in any other part of the city of Seattle. The till also is much more widespread in this northern area, and its elevation descends to at least as low as modern sea level along the north side of the Ship Canal, as well as across the canal on the extreme north point of the hill at Magnolia. Glacial fluting is not limited to till-covered areas, however, suggesting that surfaces underlain by advance outwash deposits (unit Qva) represent regions where till either was never deposited or was deposited and removed while still covered with ice. Where present, till provides a low-permeability cover to underlying aquifers, which reduces infiltration and groundwater recharge but also offers protection from surface contaminants. Till thicknesses average 2.6 m across the map area and are as great as 27 m in some boreholes. Even thicker till is exposed northeast of West Point

faster transmission of water and contaminants. Depending on subglacial conditions at the time the till was formed, as well as on postdepositional strain, the discontinuities consist of intercalated sand and silt layers, bedding planes, and (or) joints. Shortly after 17,400 (14,500 radiocarbon) yr B.P., the ice margin, which extended more than 50 km south of the map area, began to melt back. Meltwater from the ice sheet combined with runoff from the Cascade Range and drained southward and westward, spilling over divides that later were abandoned as ice pullback exposed lower divides farther north. By the time that the Seattle NW map area was uncovered by the retreating ice, proglacial drainage was well established across most of the eastern and southern lowland. Water was impounded in a lake that inundated much of the central and southern Puget Lowland, including the map area, because more than 1,000 m of glacial ice The first of two main recessional lakes (Glacial Lake Russell) drained out through the Black Hills into the Chehalis River, many tens of kilometers south of the map area (Thorson, 1980). Although the elevation of the Black Hills spillway was only about 41 m (134 ft), the ancient shoreline of Glacial Lake Russell is now higher because the land surface of the Puget Lowland has rebounded following the removal of the weight of the ice sheet. More rebound occurred in the north than in the south because the ice sheet was thicker to the north. In the center of the Seattle NW map area, rebound has been about 45 m, and so the shoreline of Glacial Lake Russell should have a present-day

elevation of nearly 90 m (300 ft). Most of the land in the map area therefore was submerged, and so little or no record of this interval remains here; much clearer expressions are found farther north (see, for example, Booth, 1987). The Seattle NW map area became ice free during the existence of Glacial Lake Russell. The second water body, Glacial Lake Bretz, was formed when ice retreated far enough north to uncover a lower spillway on the northeast corner of the Olympic Peninsula, about 40 km northwest of the map area (Thorson, 1989). As with Glacial Lake Russell, the ancient shoreline of Glacial Lake Bretz now slopes southward because of differential rebound. In the Seattle NW map area, the calculated elevation of the lake surface ranges from about 37 m (to the south) to 47 m (to the north) (approx 120-150 ft). Glacial Lake Bretz likely did not persist for more than a few decades because of rapid rates of glacier retreat (Porter and Swanson, 1998), and so thick lake deposits are not likely. The single large patch of recessional outwash deposits (unit Qvr) mapped on the north side of North Beach, which has a maximum elevation of 43 m (140 ft), likely is a subaqueous fan containing sediment derived from several upslope gullies incised into advance outwash deposits (unit Qva) along the margin of Glacial

Further retreat of the ice sheet reconnected Puget Sound to the open ocean, allowing regional water levels to fall by about an additional 40 m (Thorson, 1989). Thus, the late-glacial marine limit is near the south edge of the Seattle NW map area; farther south, any deposits associated with this recessional stage are now submerged below modern sea level because the amount of isostatic rebound has been exceeded by that of postglacial eustatic sea-level rise. A low terrace 10 to 20 m (35-65 ft) high along the east side of the hill at Magnolia, which has been included in unit Qvr, probably dates from this stage of ice retreat, but its intermediate elevation relative to the specific glacial-lake and marine water levels makes its origin somewhat enigmatic.

Postglacial Processes and Deposits Geologic activity since glaciation includes soil formation, widespread slope failure and cliff retreat, beach erosion and deposition, stream-channel erosion, and tectonic deformation. As a result of the lowered base level occasioned by the drainage of Glacial Lake Bretz, several streams in the map area began to incise the sequence of glacial and nonglacial deposits that underlies the upland surface. Yet drainage areas are so small, and stream erosion accordingly so feeble, that only the valleys of Pipers Creek (northeast corner of the map area) and of two unnamed channels on the north and south sides of the hill at Magnolia are now graded to modern sea level. On the upland surface, soil formation since deglaciation has

proceeded slowly but locally has had profound hydrologic consequences. The first meter or so beneath the ground surface usually consists of topsoil underlain by silty weathered parent material, colluvium, or fill. Where Vashon till (unit Qvt) is present, the unweathered till deposit absorbs water only very slowly. In contrast, the meter or so of soil that has developed on the till since deglaciation has high infiltration capacities and a large capacity to store and slowly release subsurface runoff. This till-derived "Alderwood" soil (Snyder and others, 1973) once blanketed about one-half of the upland plateau. The compaction or removal of that soil during typical urban or suburban development has had dramatic hydrologic effects. On areas underlain by Vashon-age advance outwash deposits (unit Qva), however, infiltration through both the soil and the parent material is relatively fast. Water permeates rapidly into the sand and then moves downward to the top of an underlying fine-grained unit, here almost exclusively the Lawton Clay (unit Qvlc). Groundwater then moves laterally to the steep hillsides along the coast and in deep ravines, where it emerges as springs

widespread, they are shown on the map only where they are more than a meter or two thick, a thickness sufficient to alter the ground-surface topography or obscure the underlying deposits. Colluvium a few centimeters to several meters thick, which covers nearly all the valley walls and slopes, consists of a mixture of locally derived materials and is principally a loosely consolidated silt, or silty sand and gravel. Small landslides, common on steep bluffs and slopes, consist of slumps and earth flows that are chiefly caused by surface erosion or spring sapping. Individual slides generally are small at map scale but can be extremely hazardous in populated areas. Some of the landslides in the Seattle NW map area, however, are quite large. The most extensive landslide complex is found along the southwest-facing bluffs of Magnolia, where winter storm waves driven by prevailing south winds maintain a steep bluff face and spring-sapping by groundwater collected from infiltrating rainwater on the till-free uplands further contributes to continued slope instability. Here, the landslide mechanism primarily is that of a block glide (Varnes, 1978), where mounding of groundwater at the contact between the overlying Vashon-age advance outwash deposits (Qva) and the underlying Lawton Clay (Qvlc) induces lateral slippage near the base of the sandy unit. This process has produced a midslope topographic bench at the elevation of the contact between units Qva and Qvlc, which commonly is about 18 m (60 ft) in this area; this bench has

proven to be irresistible for residential development for nearly a In addition to this dominant process of mass slope failures, the area is also subjected to shallow debris slides off the retreating sand face, deep-seated rotational landslides that cut through the Lawton Clay, and failure of jointed and locally stratified Vashon till directly overlying the Lawton Clay. During periods of heavy, continuous rainfall, each of these landslide mechanisms (particularly shallow debris slides) may occur. Other noteworthy landslide-prone areas are present along the Puget Sound coastline. A large, prehistoric block glide is inferred for the area immediately east and south of West Point on the basis of both topography and offsets in the contacts between units Qob and Qvlc and between units Qvlc and Qva of as much as 15 to 20 m. A smaller slide has severed a park road on the northwest corner of the hill at Magnolia over the last decade. Landslides, both shallow debris flows and deep-seated rotational slides that leave prominent midslope benches, also are abundant north of the Ship Canal. Mapped slide localities from the winter of 1996-97 (Baum and others, 2000), as well as point localities of all slides on file

ample No.	Site Name	Location (lat, long)	Altitude, m [ft]	Sample Type	Conventional 14C age, in yr B.P.1	Calibrated ¹⁴ C age, in yr B.P. ²	Reference	Map Unit	Pretreatment
W-1091	"South Beach," West Point	47.657° N., 122.425° W.	1 [3]	Wood	20,350±600	20,450 (21,750- 19,150)	Ives and others, 1964; Yount and others, 1980	Qob	Not reported
W-1181	"South Beach," West Point	47.657° N., 122.425° W.	1 [3]	Peat	22,400±800	22,550 (24,250- 20,850)	Ives and others, 1964; Yount and others, 1980	Qob	Not reported
W-1186	"South Beach," West Point	47.657° N., 122.425° W.	10 [33]	Peat	18,100±700	21,550 (23,350- 19,750)	Ives and others, 1964; Yount and others, 1980	Qob	Not reported
Beta-53736	West Point sewage treatment plant	n/a ³	-3 [-9]	Charcoal/ wood	n/a	3,455 (3,653- 3,311)	Sample EPS F1; Larsen and Lewarch, 1995	Qb	Acid-alkali wash
Beta-58026	West Point sewage treatment plant	n/a ³	-3 [-8.5]	Charcoal/ wood	n/a	4,018 (4,237- 3,852)	Sample B2; Larsen and Lewarch, 1995	Qb	Acid-alkali wash
Beta-58038	West Point sewage treatment plant	n/a ³	-0.3 [-1]	Charcoal/ wood	n/a	1,238 (1,337- 1,009)	Sample IM F9; Larsen and Lewarch, 1995	Qb	Acid-alkali wash
Beta-64761	West Point sewage treatment plant	n/a ³	1 [2.7]	Charcoal/ wood	n/a	776 (926- 703)	Sample SG F1; Larsen and Lewarch, 1995	Qb	Acid-alkali wash
Beta-64771	West Point sewage treatment plant	n/a ³	1 [3.9]	Charcoal/ wood	n/a	470 (510- 320)	Sample CL2 F1; Larsen and Lewarch, 1995	Qb	Acid-alkali wash
Beta-61325	West Point sewage treatment plant	n/a ³	2 [5]	Charcoal/ wood	n/a	280 (310-0)	Sample SB1; Larsen and Lewarch, 1995	Qb	Acid-alkali wash
Beta-64769	West Point sewage treatment plant	n/a^3	2 [6]	Charcoal/ wood	n/a	43 (150 -10)	Sample CL2 F3; Larsen and Lewarch, 1995	Qb	Acid-alkali wash
resent is considere	d to be 1950 A.D. oon age from Stuiver and Rein	ner (1993). Reported ag	e given with 2-sigma	range (in parentheses)					

Lab No.	Location	Elevation, ft	Material	Average IRSL Age, in 1000 yrs	Map Uni	
WA-4	"South Beach"	70	Laminated silt/clay	15±1	Qvlc	
WA-5	"South Beach"	75	Laminated silt/clay	13±1	Qvlc	
WA-30	Southern Magnolia	0	Silt	123±25	Qpf	

GEOLOGIC MAP OF NORTHWESTERN SEATTLE (PART OF THE SEATTLE NORTH 7.5' X 15' QUADRANGLE), KING COUNTY, WASHINGTON

Digital files available on World Wide Web at http://pubs.usgs.gov/sim/2005/2903/

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